Performance Enhancement of Hydraulic Turbine Regulating System(HTRS) Using Multi Objective Ant Colony Optimization

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Abstract- In this paper a design method for performance enhancement of Hydraulic Turbine Regulating Systemis proposed.A multi-objective Ant Colony Optimization algorithm is implemented to the PID controller ofHydraulic Turbine Regulatory System(HTRS).Multi-objectivecontroller design method is differ from single-objectiveoptimization and it has more than one objective functions.In this paper ISE and ITSE are chosen as twoobjective functions.Objective is to achieve shortest risetime and minimum overshoot simultaneously.

Index Terms- HTRS, PID controller, Ant Colony Optimization, multi-objective function, speed regulation.

I. INTRODUCTION

Hydro power is an important and cost effective renewable energy source. It plays a significant role in today's electricity generation, contributing to more than16% of electricity generation worldwide and about85% of global renewable electricity. Its benefits arevery relevant in this environment condition. Primarily it is clean renewable electricity and secondly it is asan enabler to greater contribution of other renewableson the grid.Always the generation process is not smooth. Different disturbances are emerging and it drops the stable operation of the system that is the process is nota linear one. Hence there is a need for a regulatorysystem,it is called Hydraulic Turbine Regulatory System (HTRS).HTRS includes a governor,a controller,aturbine and a generator.Conventionally the controllerused in the HTRS is a PID because of its structuralsimplicity and reliability.

II. REVIEW OF LITERATURE

ZhihuanChen[1]focused on the design of the FOPID controller using chaotic non-dominatedsorting genetic algorithm II (NSGAII) for hydraulic turbine regulating system (HTRS). Theparameters chosen of the FOPID controller is formulated as a multi-objective optimizationproblem, in which the objective functions are composed by the integral of the squared error(ISE) and integral of the time multiplied squared error (ITSE). The chaotic NSGAII algorithm,which is an incorporation of chaotic behaviors into NSGAII, is used as the optimizerto search true Pareto-front of the FOPID controller and designers can implement each ofthem based on objective functions priority. The designed chaotic NSGAII based FOPIDcontroller procedure is applied to a HTRS system. A comparison study between the optimuminteger order PID controller and optimum fractional order PID controller is presentedin the paper. The simulation and some experimental results validate the superiority of thefractional order controllers over the integer controllers

Fang H.et.al.[2]used an intelligent meta-heuristic optimization methods for the controllerdesign in the hydropower system .It recently received a lot of attentions from the contemporaryresearchers.

CoelloCACet.al [3] did an evolutionary multi-objective optimization algorithm, namelyadaptive grid particle swarm optimization (AGPSO), issued for generating a solutions set fordesigning the PID controller in the HTR system.

Naik KA.et.al. [4] observed a remarkable improvement in stability of this system with theIMC tuning method while compared with the traditional singular frequency based methodand Ziegler-Nichols closed loop optimization.

PangaoKou [5] presented a new approach of Bacterial Foraging Optimization Algorithm (BFOA) is introduced in this study. Toimprove the precision of the identification process, amodified objective function is proposed based on the measurement of gate opening, mechanicaltorque and generator speed from a simulated model. The improved objective function (IOF) and the conventional objective function (COF) are used in the identification and twosets of parameters are derived and compared. The results show that BFOA is effective inidentification of hydraulic turbine governor system and parameters derived from the modifiedobjective function have a higher accuracy.

KanasottuAN [6] introduced a remarkable improvement in stability of this system hasbeen observed with the IMC tuning method while compared with the traditional singularfrequency based method and Ziegler - Nichols closed loop optimization.

JagatheesanKaliannan.et.al [7] describe the application of an Artificial Intelligence (AI)optimization technique to design Proportional-Integral-Derivative (PID) controller for LoadFrequency Control (LFC) of single area re-heat thermal power system.

Rajeev Kumar [8] studied different PID tuning formulas for a third order process.Theyare based on the knowledge of the ultimate gain, ultimate period and minimization of integral squared error (ISE) and integral absolute error (IAE).The performance of various tuningmethods has been compared by applying a step input to the given process. Simulation resultsshow that tuning a PID controller with Ziegler Nichols (ZN) tuning method results inless rise time (tr), peak time (t_p), and integral squared error (ISE). The Relay Auto tuningmethod is applicable when less ISE is required while Modulus Optimum (MO) tuningmethod is applicable when less settling time (t_S) and less overshoot is required and ComputationalOptimization (CO) method is helpful when the desired closed loop specificationsare decided by the designer. The robustness factors gain margin (GM), phase margin (PM),gain crossover frequency, phase crossover frequency and stability are considered.

Chuanwen Jiang et.al [9] proposes an improved evolutionary programming (EP) methodwith deterministic mutation factor for on line PID parameters optimization of hydro turbinegoverning systems. The mutation factors are usually generated with Gaussian or Cauchyrandom series in conventional evolutionary programming algorithms.

EnsiEnim et.al.[10] treat a tuning of PID controllers using multi-objective ant colonyoptimization. The design objective was to apply the ant colony algorithm in the aim oftuning the optimum solution of the PID controllers (Kp, Ki, and Kd) by minimizing themulti-objective function. The potential of using multi-objective ant algorithms is to identifythe Pareto optimal solution.

III. MODEL OF THE HYDRAULIC TURBINE REGULATING SYSTEM

Usually a hydro power plant consists of a reservoir, penstock,wicket-gate,water turbinewith generator sets attached and the draft tube.Water from the reservoir flows through thepenstock and then is regulated by means of guide wicket gates,which are always moved by ahydraulic servo mechanism controlled by turbine speed controller. The controller acts whenthere is a mismatch between the torque developed by turbine and the electrical demand onthe synchronous generator.HTRS is focused on the frequency control among the given speedreference r, controller output u, servomechanism device output y, water turbine mechanicaltorque output m_t and flow rate q, conduit output h, and generator speed output x.In this section, a kind of non-linear models of HTRS has been studied and models of othercomponents are added respectively. Read already published work in the same field.

3.1 Model of turbine governor

PID is the widely used controller for speed governing of HTRS. The transfer function of the PID controller is

$$GPID(s) = K_P + K_I/s + K_D s \qquad (3.1)$$

K_P =Proportional gain, K_I =Integral gain, K_D =Derivative gain

3.2 Model of servomechanism

The servomechanism plays the role of actuator of water turbine. It is made up by the major servomotor and auxiliary servomotor, thus the model can be conducted as a first ordersystem.

$$Gc(s) = \frac{1}{Ty(s)+1} \qquad (3.2)$$

Where, Ty is major servo time constant

3.3 Model of water turbine and penstock system

In HTRS, it usually considered water turbine and the penstock pipeline as a whole. As flow rate is nonlinear to pressure, It isdifficult to describe movement laws of fluid in the penstock.However,neglecting plant parameter changes and water column elasticity effect inthe penstock,the transfer function of inelastic water hammer could be expressed as

$$Gh(s) = \frac{h(s)}{q(s)} = T_w s \qquad (3.3)$$

Where, h(s) and q(s) are the Laplace transform of effective water head h and flow rate q.T_w is known as water response time constant.

The dynamic characters of turbine and penstock system can be expressed as

$$Gt(s) = e_y \frac{1 - emTw}{1 + e\ qhTws} \qquad (3.4)$$

3.4 Model of generator system

Model of the synchronous generator used in this section is a simplified first order transferfunction

$$Gg(s) = \frac{1}{Tas + en} \qquad (3.5)$$

Where, Ta is the inertia time constant of generator, en is the adjustment coefficient of generator.

IV. MULTI-OBJECTIVEANT COLONYOPTIMIZATION ALGORITHM ONHTRS

The ACO was first proposed by Marco Doriga, Vittorio aniezza and Alberto Colorni in1995. The main duties to be done in an ACO algorithm are the solution construction,themanagement of pheromone trails, and the local search.In addition to that there is a needto initialize the data structure and parameters.The blind ant deposit a chemical substancecalled pheromone on their path for mutual communication.While each ant starts initially atrandom positions and each of them moves in search of food source,the one that finds foodsource first returns the nest first and that makes the shortest distance and more number oftravels between the food and the nest.Thus the pheromone content becomes stronger andrest of them uses this path.ACO has been tested over various of problems such as travelingsales man problem, generation scheduling etc.ACO based real time optimization has started.

4.1 Application of Ant Colony Optimization for HTRS

The development of Ant Colony Optimization based algorithm can be described as follows. The various steps involved are

4.1.1 Data Initialization

In this step,(1)the instance has to be read,(2)the distance matrix has to be computed,(3)thepheromone matrix has to be initialized,(4)the ants have to be initialized,(5)the algorithm'sparameters must be initialized,(6)some variables that keep track of statistical informationsuch as the used CPU time, number of iterations, or the best solutions found so far, have to beinitialized.A data initialization procedure is like as follows:

a) Initialize Data
b) Readinstance
c) ComputeChoiceinformation
d) Initialize Ants
e) Initialize Parameters
f) Initialize Statistics
g) End-procedure

4.1.2 Solution Construction

The optimization is managed by the procedure *Construct Solutions*.It includes these phases; the ant's memory must be emptied. And deploying ants initially: In this task ants are randomly deployed in a feasible solution
space with respect to the constraint.Here,the position of an ant represents onecomplete solution set of the problem.In this problem there are three parameters tobe optimized,vizKp, Ki, Kd.So the location of an ant is the point in the three dimensional space having axes Kp, Ki, Kd.
Each ant constructs a solution set.at these procedure ants apply a *Decision rule*to find outthe probability of next node from current node. At first the current node of each ant is determined.The probabilistic choice of next node is calculatedby equation

$$Pij^{A}(t) = [\tau_{ij}]^{\alpha}[\eta_{ij}]]^{\beta} / \sum_{ij} [\tau_{ij}]^{\alpha}[\eta_{ij}]^{\beta} \quad (4.1)$$

ACO uses a pheromone matrix $\tau = \tau_{ij}$for the construction ofgood solutions.

4.1.3 Local Search

Once the solutions are constructed, they may beupdated by a local search procedure. Since the details of the local search are not important for understanding how ACO algorithms canbe coded efficiently.

4.1.4 Pheromone Update

One of the critical step in an iteration is the pheromone update.It includes two pheromoneupdate procedure; Pheromone evaporation and pheromone deposit.The pheromone evaporationdecreases the value of pheromone on the path of the ants by constant factor ρ.Thepheromone deposit adds the pheromone strength to the path of the ants.The pheromone content injth location is given by the equation

$$\tau_{ij}(t) = \rho(\tau_{ij}(t-1)) + \sum_{A=1}^{NA} (\Delta.\tau_{ij}^{A}(t)) \quad (4.2)$$

Where NA: number of ants, and ρ : the evaporation rate $0 < \rho < 1$.

4.1.5 Termination Condition

The program stops if at least one termination condition applies.Usual termination conditionsare;(1)The algorithm has found a solution within a predetermined distance from a lower boundon the optimal solution quality.(2)A maximum number of tour constructions or a maximumnumber of algorithm iteration has been reached.(3)A maximum CPU time has beenspent.(4)The algorithm shows stagnation behavior.
The flow chart for ACO algorithm is presented in Figure 4.1

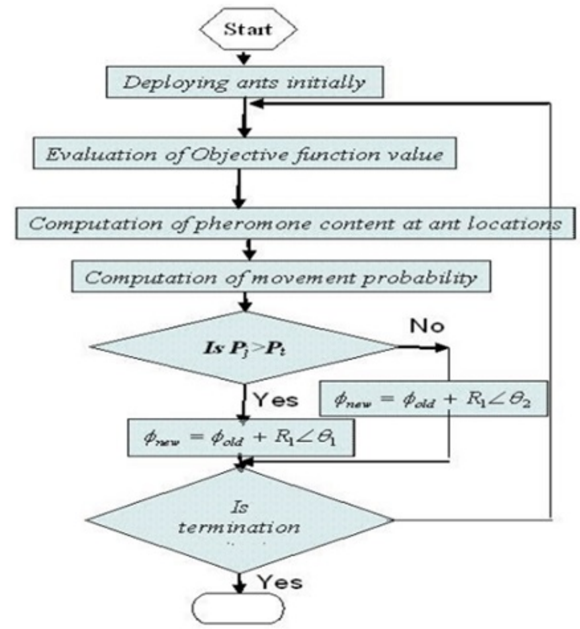

Figure 4.1 ACO flowchart

V. MULTI-OBJECTIVE FUNCTION

The regulators used in HTRS are usually a PID controller.So the system performance strictlydepends on the PID gain values.It is desirable to reduce raise time and decrease damp oscillations simultaneously.Thus objective functions to be selected will carry the responsibility.Objective functions respected to the rise time and damp oscillations are considered for theoptimization of PID controller.They are: Integral of squared error(ISE) and Integral of time multiplied squared error(ITSE).

$$ISE = \int e^{2}(t)dt \quad (5.1)$$

$$ITSE = \int te^{2}(t)dt \quad (5.2)$$

e(t)is the error signal and t is the time .
Objective function ISE tries to ensure shortest rise time and the second objective function ITSE tries to eliminate damped oscillations. Both objective functions must be minimized for effective operation of control loop. Lower value of ISE makes the system faster and minimizing ITSE ensures to eliminate oscillations.

VI. RESULTS AND DISCUSSION

The performance of the system with proposed ACO based HTRS has been examined through dynamic analysis for various system loading conditions such as no load and on load. The steps mentioned in the above chapter are used for HTRS design.

Dedicated program is developed in MATLAB for the implementation of the ACO algorithm. The system parameters taken are listed in table 6.2. The parameters used in the implementation of ACO are listed in table 6.1.Parameter variations of ACO based system under no load and on load are shown in figure6.1 and Figure 6.2 respectively.

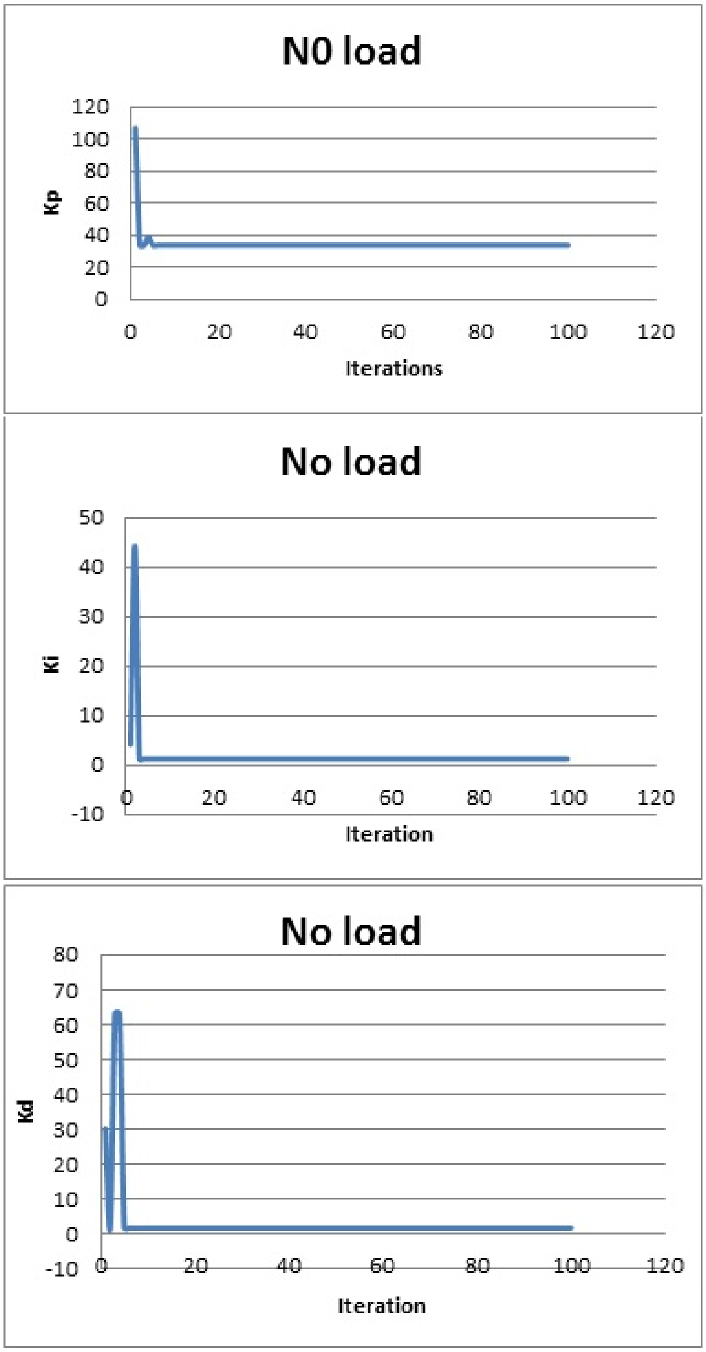

Figure 6.1 Parameter variation under no load condition

Ant population	10
No.of iterations	100
Evaporation constant	0.7
No.of nodes	10000

Table 6.1ACO data

Running Condition	No load	On load
ey	0.9080	1.40
eqy	0.7887	1.23
eh	1.4191	0.35
eqh	0.4571	0.15
en	0.45	0.45
Ta	12	5.72
Tw	0.83	0.83

Table 6.2 System parameters

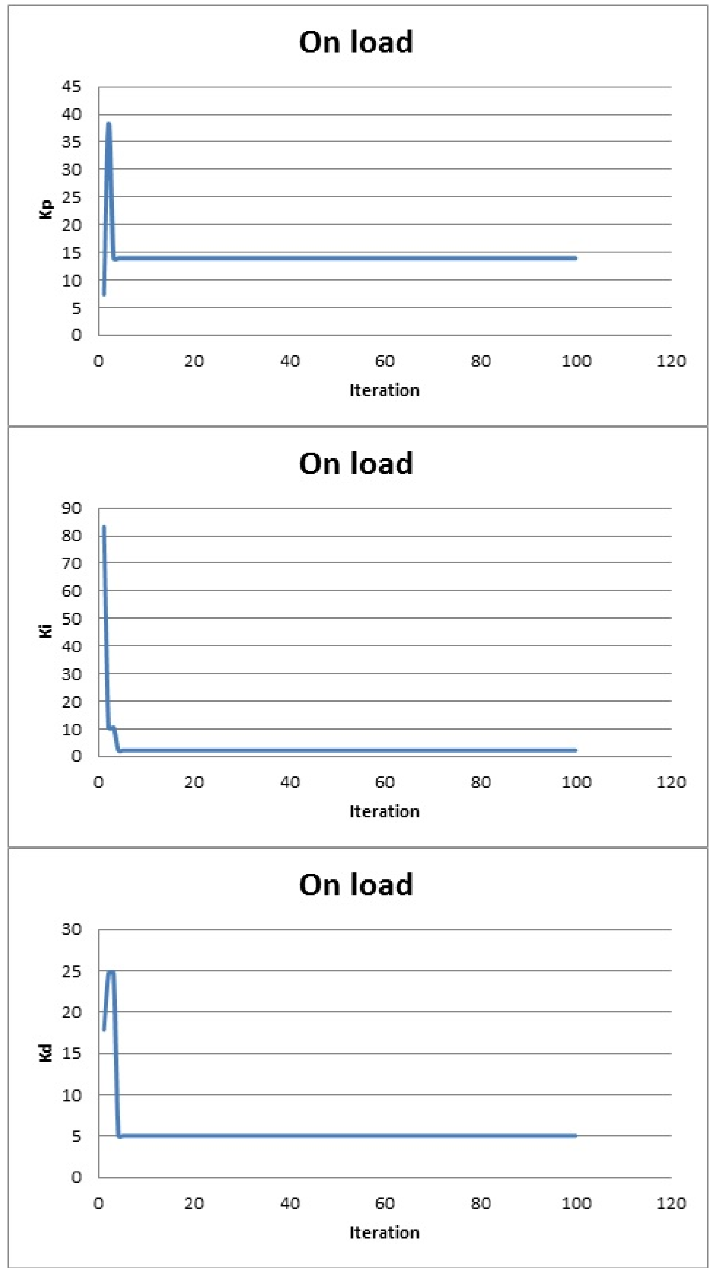

Figure 6.2 Parameter variation under on load condition

The step responses of the ACO based HTRS underno load condition and on load conditions are shown in Figure 6.3, Figure 6.4 respectively.The time domain specification of ACO based HTRS under no load and on load conditionsare compared.Figure 6.5 shows the comparison

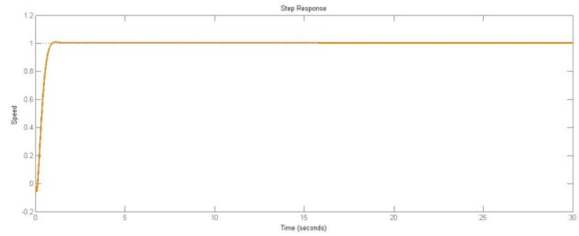

Figure 6.3 No load step response of ACO based HTRS

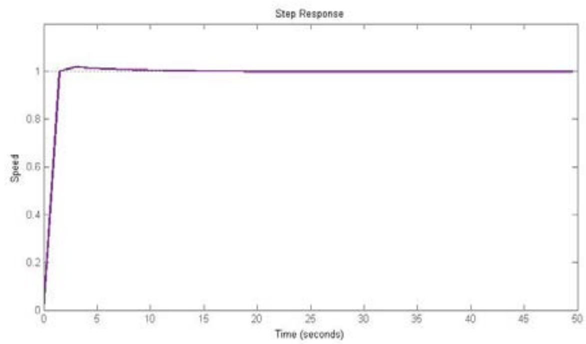

Figure 6.4 No load step response of ACO based HTRS

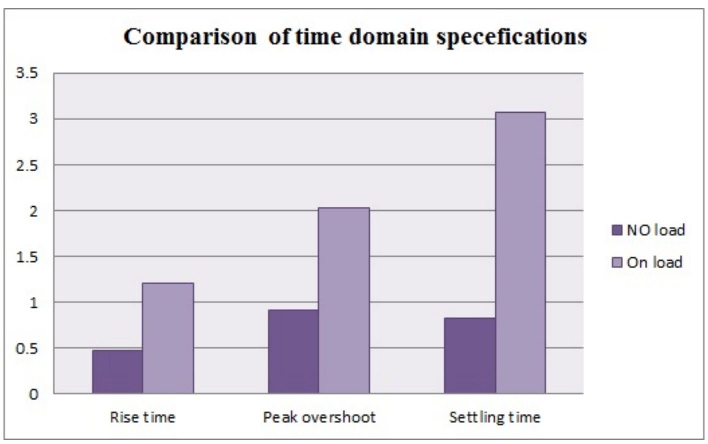

Figure 6.5 Comparison of time domain specification of ACO based HTRS under no loadand on load conditionsHTRS

VII. CONCLUSION

Ant Colony Optimization has been successfully employed in recent times for the optimal identification of system parameters. In this work multi-objective Ant Colony Optimization algorithm is proposed for the performance enhancement of Hydraulic Turbine Regulating System. The robustness and convergence characteristics of proposed algorithm based on the foraging behavior of ants are analyzed and presented. It is observed that all ants distributed in bounded solution space coherently converge to the global optima with lesser number of iterations as natural ants do while foraging. ACO ensures the better performance of the system with shortest Rise time and minimum Overshoot.

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